OUR NEAREST STAR, THE SUN[1]

By Charles E. St. John

If the Sun were removed to eight times the distance of its nearest stellar neighbor, it would appear among the fainter stars, just fairly visible to the unaided eye. Like the other stars, it is self-luminous, but among them it is conspicuous only because of its relative nearness, as there are many other stars that surpass it in size and greatly excel it in luminosity. The blazing *Sirius*, the brightest star in all the sky, has 3.4 times the mass of the Sun and sends out 48 times the light, but even it is far surpassed in absolute luminosity by other giant stars.

Nevertheless the importance of the Sun to us is typified by its apparent prominence in the heavens, for, in a very real sense, we are children of the Sun. The Earth is held in her path by the invisible attraction of the Sun, a pull greater than could be exerted by a bond of steel hundreds of miles in diameter; or, as Young puts it, it would be necessary to cover the whole Earth with wires as large as telegraph wires and only about half an inch apart in order to get a metallic connection that would stand the strain. Not only is the motion of the Earth in space controlled by the masterful Sun, but what is more directly evident, the Sun is the source of practically all our light and heat, without which life, as we know it, could not exist upon the Earth. Some one has said that if the Earth were cut off from all solar radiation for a single month, all life would be extinguished and the world become a frozen waste.

It is not so evident, but as clearly true, that the energy stored in wood, coal, oil and gas has come to us from the Sun. Under the influence of sunlight, particularly of the red and blue components, the carbon dioxide of the atmosphere is taken in by the leaves of trees and plants and acted upon to form the complex constituents of plant growth, mainly compounds of carbon with hydrogen, oxygen and nitrogen. Their chemical transformation requires the absorption of energy which is accumulated and stored in these compounds, to be released and again transformed when they are burned rapidly in ordinary combustion, or slowly in our own bodies. Every heart beat, every breath we take, every thought, and every act performed draws its working power from the accumulated solar energy stored up in plant and animal growth. The transformation

[1]Adolfo Stahl Lecture.

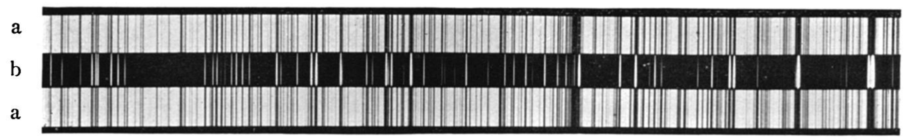
of solar energy in plant growth takes place in the leaves under the action of sunlight upon the green coloring matter, the chlorophyll. As heat engines plants cannot be considered efficient, transforming as they do only one or two per cent of the solar energy falling upon their leaves, but the energy supplied, as will appear later, is enormous; plants work continually during growth and store up energy in permanent form; these are favorable conditions and result in tremendous advantages for man. The energy of coal has waited for his touch many millions of years and what, if any, escapes his wasteful use will endure uncounted millions yet without loss of its potential energy. The energy of the Sun is stored in the water lifted into the atmosphere by the Sun's power and carried by wind-driven clouds to higher regions, where it falls as rain or snow, ever renewing the reservoirs and so rendering them a practically exhaustless source of power.

The study of the Sun is of interest not only for its immediate importance to us, but because the Sun is the only star near enough to us to allow of intensive and detailed study. For a proper orientation it may be well to consider some of the tremendous magnitude relations of the Sun.

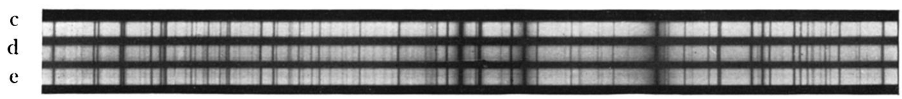
The diameter of the Sun	863,000 miles
The distance from the Earth	93,000,000 miles
The mass of the Sun	332,000 x Earth
The mass of the Earth	6.58×10^{19} tons
The mass of the Sun	2.19×10^{27} tons
Distance to nearest star	25×10^{12} miles

It is impossible for us to conceive the meaning of such colossal numbers, but they may serve to indicate relations, and it will not seem surprising that we know so little but rather amazing that we have learned so much concerning bodies at such inconceivable distances, that the human mind has been able to bridge such vast spaces and bring to our knowledge more and more the secrets of the universe.

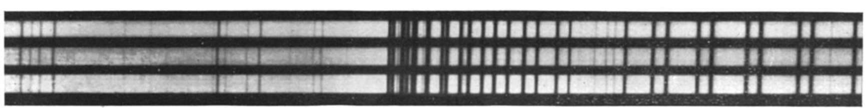
The advancement of our knowledge of the Sun and stars depends in great measure upon the analysis of light by the spectroscope, an instrument by which the white light of the Sun is stretched out into a spectrum, that is, a narrow band of colors extending from red thru yellow, green and blue, to violet, crossed at right angles by a vast number of narrow dark lines. It is to these dark lines, the Fraunhofer lines, that the solar investigator gives his attention



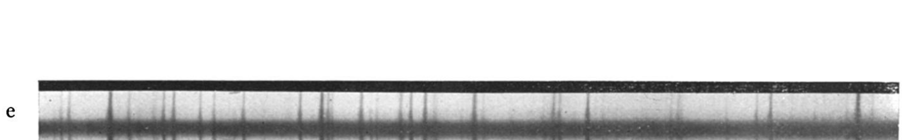
(1) Coincidence of bright lines (a) from iron vapor with dark lines (b) in the Sun's spectrum, violet region, λ4200.



(2) Displacement of the lines at the east (c) and west (d) limbs of the Sun, green region. λ5167.



(3) Lines of B group due to oxygen in the Earth's atmosphere undisplaced by Sun's rotation, red region, λ6867.



(4) Displacement of the lines on the near (e) and far (f) sides of a sun-spot showing outflow, blue region, λ4765.

PLATE I

rather than to the brilliantly colored band. From the changes in the relative positions, intensities, and other characteristics of these dark lines, he determines the substances in the Sun, the pressure and motions in the atmosphere, the law of its rotation, the temperature and magnetic effects in sun-spots, and endeavors to find answers to the many as yet unsolved problems. The spectrum is to most people a kind of unknown language. The interpretation of its message from the Sun and the far more distant stars is the special work of the astronomer. He finds the key to it in the physical laboratory, which forms an essential part of a modern solar observatory. When in the laboratory a substance like iron, for example, is turned to vapor at a very high temperature, the iron vapor becomes luminous and emits a characteristic light. This light when analyzed by a spectroscope yields, not a band of colors, but a series of narrow bright lines scattered thru the red, yellow, green, blue and violet. Each element when in the form of vapor may be made to yield a line spectrum which distinguishes it from every other element and furnishes the means for its positive identification. Moreover, incandescent vapors absorb from white light passing thru them precisely the rays which they by themselves emit, so that under suitable conditions of temperature and emission, the spectrum of the transmitted white light shows dark (absorption) lines in the exact positions of the bright lines that characterize the spectrum of the vapor, and these dark lines serve equally well for its identification.

These principles are used in the identification of substances in the atmosphere of the Sun and stars. The vapors and gases in these atmospheres, tho at temperatures of thousands of degrees, are cooler than the source of the white light originating lower down and, as this passes thru them on its way to us, it impresses upon its own spectrum their characteristic absorption lines. A portion of the violet region in the spectra of the Sun and the glowing vapor of iron is reproduced in Plate I (1). The coincidence between the bright lines of the iron spectrum and dark lines in the Sun's spectrum is complete and shows therefore the presence of incandescent iron vapor in the solar atmosphere.

Of the 92 elements indicated by the periodic system all except five or six have been found upon the Earth, some in minute amounts only. The number of elements identified with certainty in the Sun is 38 and includes the common metals—iron, nickel, copper, zinc,

lead, tin. Of most of the heavy metals such as gold, platinum, iridium, and uranium there is no positive evidence. If they are represented at all in the solar spectrum it is only by the faintest lines. The absence of definite evidence of the presence of these heavy elements in the Sun may be due in part to their actual rarity. If the 92 possible chemical elements be arranged in the order of increasing atomic numbers, it is found, as Professor Harkins points out, that the comparatively light elements occurring in the first third of the series supply 99 per cent of the substances in the Earth's accessible crust and in meteorites: i. e., two-thirds of the elements, the heavier ones, furnish only a fraction of one per cent of the Earth's crust and of the cosmic material represented by the meteoric visitors from interstellar space. If the proportions between the light and heavy elements and their distribution in the Sun are comparable, as seems probable, with the proportions and distribution in terrestrial sources, there can be at most only traces of them in the lower levels of the solar atmosphere and it is not surprising that we have not yet detected them with certainty. The groups of non-metallic elements such as chlorine and bromine, oxygen and sulphur, nitrogen and phosphorus, are not represented in the solar spectrum by their characteristic lines, except possibly oxygen and nitrogen. The suggested explanation is found in the observation that the presence of metallic vapors tends to suppress the spectra of the non-metals when the two classes of substances occur in the same mixture.

As a locomotive whistle is higher in pitch when approaching than when receding, so light coming from a rapidly approaching source is bluer, and from a receding source is redder, than when the source is at rest; this manifests itself in the spectrum by a slight displacement of the lines toward the violet or toward the red according as the source is approaching or receding. This is known as the Doppler effect. In Plate I (2) are shown narrow spectra taken from the east and west edges of the Sun on the line of the equator, the two outer from the west and the central one from the east edge. When carefully examined, it is seen that the lines are slightly displaced, the lines of the central strip are to the left, that is, to the violet of those in the outer strips. From a microscopical measurement of the displacement $\Delta\lambda$ in terms of the wave-length λ and the observed velocity V of light, the velocity with which the east edge of the Sun is approaching and the west edge receding is found from

the formula $v = \frac{\Delta\lambda}{\lambda} V$ to be approximately 2 km. per second or nearly 4500 miles per hour. It follows that the equatorial region of the Sun turns on its axis once in 24.5 days. The rotation is slower for higher latitudes, and from this it is evident that the Sun does not rotate as a solid. As these differences in rotation are probably vestiges from the past, a complete knowledge of the Sun's rotation is important in the development of solar theory.

Selective absorption occurs also in the Earth's atmosphere, but in this case the absorbing matter is at rest relative to the observer and the lines of terrestrial origin remain undisplaced in spectra from the east and west edges of the Sun. This furnishes a means of distinguishing between solar and terrestrial lines. Fig. (3) Plate I reproduces such a spectrum showing the great B group due to oxygen in the Earth's atmosphere, the systematically spaced lines occurring in the deep red. These are undisplaced while the weaker lines of solar origin are all distinctly shifted. This is seen especially well in the group of four solar lines to the right of the middle of the plate.

Another application of the Doppler effect is the study of the currents in the solar atmosphere around sun-spots. It is found that in the lower levels of the Sun's atmosphere the flow from spots is outward along the Sun's surface, and inward for the higher lying vapors which are rushing into spots with tremendous cyclonic whirls. Since the Sun is a globe, the flow outward from a spot near the Sun's limb is toward the observer on the near, and from the observer on the far, side of the spot.

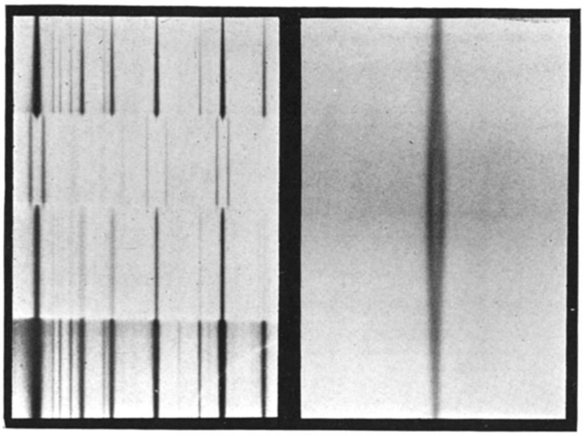
In Fig. (4) Plate I the spectra from the two sides of a spot are shown juxtaposed. Along the line of juxtaposition the lines in the spectrum from the near side are displaced to the violet and those from the far side are displaced to the red, indicating in both cases a flow outward. The displacements are largest for the faintest or low-level lines. They become smaller and smaller as stronger and stronger lines are observed until for the strongest lines in the Sun's spectrum, the H and K lines of calcium, the hydrogen lines and the strongest lines of sodium, magnesium and iron, the displacements are in the opposite direction indicating an inflow for the high-level vapors. From the amount of displacement it is possible to determine the relative distribution of the constituents of the Sun's atmosphere. In this way it is found that the vapors of the heavy and rare elements occur only at the lower elevations,

and that the lighter and more abundant substances are distributed over a far wider range of altitude, some of them forming the indefinite boundary of the Sun.

The surface of the Sun, the photosphere, ordinarily appears to the unaided eye as a brilliant disk without markings of any kind, but when photographed or observed with the telescope the surface appears distinctly granular, with bright mottlings upon a dark background. The bright patches, 300 or 400 miles in diameter, are thought to be the tops of rising columns of hot vapors. Often spots many thousands of miles across are seen, each with a dark center, the umbra, surrounded by a shaded area, the penumbra. The umbra is only dark, however, in comparison with the brilliant photosphere, as its temperature, tho lower than that of its surroundings, is comparable with the highest terrestrial temperatures. These features may be recognized in the reproductions of Plate II (Frontispiece); (a) is from a direct photograph and shows granulations, faculae and spots; (b) shows the same region photographed with light from the hydrogen in the upper solar atmosphere. In this the streaming, whirling movement of the hydrogen gas is distinctly seen and represents a cyclonic storm of vast extent.

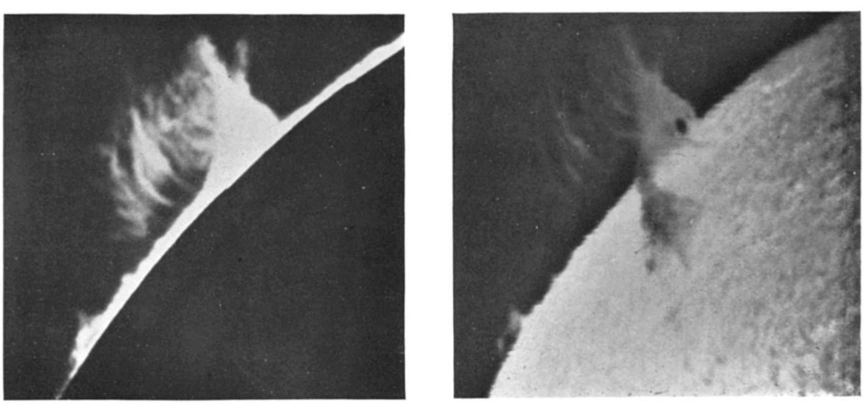
The umbra of a sun-spot is, as Hale discovered, a powerful magnetic field. This is shown by comparing the behavior of the spectrum lines in spots with their behavior when the radiating vapor is in a strong magnetic field. In the laboratory under such conditions, many lines are separated into components with characteristic properties, the Zeeman effect. That the lines behave in the same way in the spectra of spots furnishes positive evidence that a magnetic field exists in the umbra of a sun-spot. The doubling of the lines when light is produced in a magnetic field is shown in (a) Plate III, and in (b) the doubling in the umbra of a sun-spot.

During a total eclipse of the Sun great red-colored prominences are often seen extending many thousands of miles beyond the limb. These are mainly clouds of hydrogen and calcium vapor and take their color from the strong red light emitted by glowing hydrogen. These are now recorded daily by covering the Sun's image with a circular disk, thus producing an artificial eclipse, and photographing them by the spectroheliograph, an instrument by which the surface of the Sun and its surroundings can be photographed in the light of a selected spectral line. In (c) and (d) Plate III, a



a b

(a) Doubling of lines in the magnetic field.
(b) Doubling of line in the umbra of a sun-spot.



c d

(c) Detail of prominence beyond the limb, Ellerman.
(d) Detail of its projection in the disk, Ellerman.

PLATE III

prominence is shown photographed in this way by Mr. Ellerman, with a long exposure to get the detail beyond the limb and with a shorter exposure for the detail of the portion of the prominence projected on the disk. The two photographs show that certain dark markings on the Sun's disk brought out only by the spectroheliograph are prominences in projection; that is, intervening masses of cooler vapor high above the visible surface of the Sun. These absorb from the transmitted photospheric light more light of their own rate of vibration than they send towards the Earth, so that in light of this particular color or wave-length they appear dark against the hotter and hence brighter background of the disk. It is the characteristic property of the spectroheliograph to "see" the Sun photographically in the light of any selected wave-length. The illustrations in Plate III (c) and (d), colored the proper shade of red, that of the red light of hydrogen, would represent the Sun as seen by an eye sensitive to this particular color and blind to all others.

As it is possible by working with the slit of the spectrograph close to the edge of a large image of the Sun to see and to photograph in full sunlight the "flash" spectrum, the bright lines given by the Sun's gaseous atmosphere when the white disk is just covered by the Moon at a total eclipse, there remains but one of the recognized solar phenomena that requires for its observation the conditions obtaining only at a total solar eclipse, namely, the corona, an extensive halo of greenish pearly light so faintly luminous that the sunlight diffused in the Earth's atmosphere renders it invisible except when that light is cut off by the Moon at a total eclipse. The coronal light is thought to arise partly from sunlight by a kind of dust-fog around the Sun, and partly from a hypothetical element, coronium, giving a characteristic green ray that corresponds to nothing known in the Sun or upon the Earth. This lends the corona a peculiar interest and together with the uncertainties concerning its nature and relationship to the Sun must for a long time give it prominence in the program of eclipse observations.

The Sun is by no means a quiescent body. Variation in its activity is indicated by the increase or decrease in the size and number of spots, faculae, and prominences, and within the last decade the measurement of the heat radiated from the Sun has become so delicate and exact that variations in its amount have been established by the observers of the Smithsonian Institution.

Numerous efforts have been made to discover connections between changes in the Sun and terrestrial phenomena. Sun-spots, faculae, and prominences increase together to a maximum number, decrease to a minimum, then rise again to a maximum in regular sequence, that is, they show a definite periodicity. The question may be raised, Are there phenomena on the Earth that run the same periodic courses? If terrestrial changes manifest the same orderly sequence over a long series of years we would be justified in assuming a connection between the solar and such terrestrial phenomena. Sun-spots have been observed for a hundred and fifty years. When the spot numbers are plotted for the different years the resulting curve shows that they occur in cycles and that the average period of the cycle from maximum to maximum is 11.1

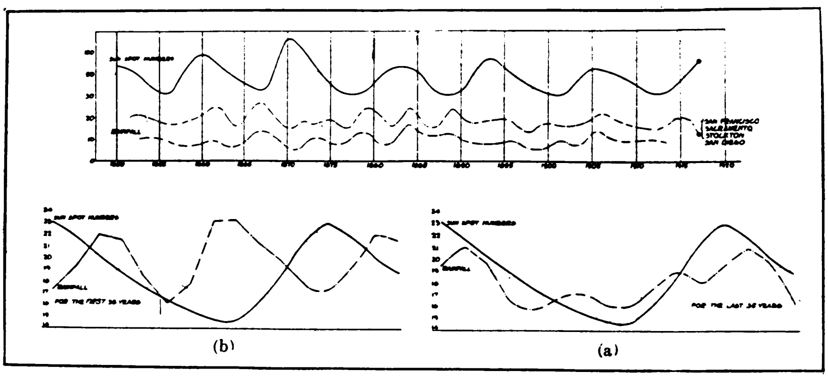


FIG. 1. Comparison of rainfall with sun-spots.

years. The magnetic elements of the Earth show, aside from the secular and regular daily variations, irregular fluctuations in intensity: the so-called magnetic storms are examples of extremely vigorous disturbances of this character. When the sun-spot and magnetic variation curves are compared, they are found to be identical in period and the peculiarities in one are matched by similar peculiarities in the other. No one questions their intimate connection, but when an effort is made to correlate the weather, the rainfall for example, with sun-spots it has not been possible to establish other than occasional coincidences. It may be interesting to compare the rainfall in this section of California with the sun-spot curve. Records at San Francisco, Stockton, and Sacramento are available for nearly seventy years. Such a comparison is shown in the curves in Fig. 1. At once it is seen that the years of maximum

rainfall coincide with neither the maximum nor the minimum of the sun-spot curve. The danger of basing a conclusion upon too limited data is illustrated in the two short curves in Fig. 1. Curve (a), a composite for the last 35 years, shows an approximation to similarity with the spot curve, while curve (b), for the first 35 years shows complete dissimilarity. No one has been able to suggest any good ground for suspecting a direct connection between sun-spots and rainfall; but when it is found by observations that there are changes in the amount of heat sent to us from the Sun's abounding store, we would seem to be justified in expecting to find a direct relation between terrestrial temperatures and variations in solar radiation, as the Earth's temperature is a function of the Sun's heat emission. We would expect to find a general rise in temperature with increased solar radiation, but even here the matter is not so simple. During a sun-spot maximum the Sun sends us 3 or 4 per cent more heat than during the minimum. The spots are not directly concerned in this increased radiation, they are only symptoms of the greater activity of the Sun. The solar gases are in a more turbulent state and bring more heat from the hot interior to the surface during the periods of increased activity. This change of 3 or 4 per cent is distributed over a space of 5 or 6 years and hence is slow in producing its effect, but fluctuations of 5 or 6 per cent that run their course in a week or ten days are shown by the Smithsonian observations. The temperatures at fifty stations well distributed over the Earth have been correlated by Dr. Clayton with the indicated short-period fluctuations in the solar radiation. The results are surprising. In the equatorial regions the temperatures rise with increased solar radiation, but in the Earth's temperate zones the temperatures fall. At Pilar, Argentina, increase of temperature followed increase of solar radiation and reached the maximum effect in one or two days, while at San Diego, California, decrease of temperature followed increase of solar radiation, and the maximum effect occurred after three or four days. Manifestly secondary causes are set in motion which in part mask the direct solar action in the temperate zones. The Sun being more nearly overhead in the equatorial regions, the influence of increased radiation is there more quickly felt, the temperature of the atmosphere is increased and the abnormally heated air rises and overflows the temperate zones, producing conditions that disturb, in a way unknown as yet, the blanketing effect of the atmosphere. A

similar paradoxical result appears in the lower temperatures of the world in general at sun-spot maximum than at minimum, tho the solar radiation is greater at sun-spot maximum. The observed lowering in temperature is about one degree Fahrenheit while the increased radiation of the Sun indicates, according to Abbot, a rise of some three or four degrees.[1]

The measurement of the solar constant, the total intensity of solar radiation outside the Earth's atmosphere at the Earth's mean distance from the Sun, as made by the observers of the Smithsonian Institution at the Washington, Mount Wilson and Mount Whitney stations, is 1.95 calory per square centimeter per minute and it is thought that future investigation will make no considerable change in this value. The amount of energy represented by this radiation is difficult of conception. Assuming, as we have reason to do, that the Sun radiates equally in all directions we can easily calculate the total emission, as it is 1.95 calory per minute on each square centimeter of a sphere whose radius is the mean distance of the Earth from the Sun, that is, 93,000,000 miles or 15×10^{12} centimeters.

Total emission $= 1.95 \times 4\ (15 \times 10^{12})^2$ calory per minute. This is sufficient, as Abbot calculates, to melt a layer of ice 426 feet thick in a year. A layer 426 feet thick over the cross-section of the Earth is equivalent to a layer 106.5 feet over its surface, so that we can say that the heat received by the Earth in a year is sufficient to melt a surrounding shell of ice 106.5 feet thick. Abbot further calculates that the melting in a year of a shell of ice 426 feet thick surrounding the Sun at the Earth's mean distance would represent as many heat units as the burning of 4×10^{23} tons of anthracite coal or a mass of coal 60 times the mass of the Earth.

The great terrestrial sources of heat are combustion and the transformation into heat of electrical energy obtained from water power. If we try to account for the Sun's heat by combustion we reach an absurdly small result for the life of the Sun. We have just seen that the yearly output of heat is equivalent to that from the burning of 4×10^{23} tons of coal. If the Sun were composed of pure coal its combustion would supply the heat loss only for $\frac{2.19 \times 10^{27}}{4 \times 10^{23}} =$ 5,500 years, a moment only in the life history of the Sun-Earth system.

[1] *The Sun and the Weather*, Dr. C. G. Abbot, *Scientific Monthly*, November, 1917.

It has been suggested that the maintenance of the solar radiation is due to the continued fall of meteoric matter into the Sun. A mass coming from an infinite distance would acquire a velocity of 610 kilometers or 385 miles per second at the surface of the Sun and when brought to rest would disengage 6,000 times as much heat as would be produced if it were coal burning in oxygen. To compensate for the loss of radiation would require that 22 pounds of matter fall upon each square yard of the Sun's surface per hour. This would increase the diameter of the Sun so slowly that 35 millions of years must elapse before the increase would attain one second of arc. It would, however, increase the mass of the Sun to such an extent that the effect could not escape detection. Bosler calculates that in the last 2,000 years the accumulation would have been sufficient to change the orbital motion of the Earth by 1/8 of a year, a change, needless to say, that has not occurred. Moreover, few meteors coming from interstellar space would fall into the Sun as most of them would circulate around it as comets do.

A source of heat that has been very generally admitted since its suggestion by Helmholtz, is the gravitational attraction of the Sun upon its own material, as a gradual falling of the Sun's substance toward the center would transform the potential energy of gravitation into heat. The estimates of the energy available in the past from this source are based upon the contraction of the Sun to its present size from a diameter exceeding that of the orbit of *Neptune*, the outermost known member of the solar system. The energy supplied by this contraction would have sustained the present rate of radiation for approximately 25,000,000 years. According to Newcomb the Sun will have shrunk to half its present diameter in 7,000,000 years and will be unable to furnish heat sufficient to support life as we know it for more than 15,000,000 years.

Tho the gravitational contraction of the Sun is regarded as a real source of energy, it is generally admitted that it alone is not sufficient to account for radiation thru the enormous periods of time required for the geological transformation of the Earth. In the effort to meet this recognized difficulty the suggestion has been made that the solar radiation was less intense during past ages than at present, the deficit being supplied by the inherent heat of the Earth or by receiving heat from a large solid angle subtended by a greatly extended nebular Sun. And since the discovery of the liberation of energy by the breaking up of radioactive substances,

much attention has been given to the suggestion that the presence of such substances in the Sun would assist in maintaining the solar radiation and give it sufficient duration to meet the requirements of geological transformation. Direct proof of their presence in the Sun is lacking, tho the occurrence of helium in the Sun, a product of the disintegration of radium, may be taken as indicative of their possible presence. That the lines of radioactive elements do not occur in the solar spectrum is not surprising in view of their high atomic weights. If radium and its parent element, uranium, do exist in the Sun, they are probably at a very low level in the solar atmosphere and their lines would consequently be extremely faint or absent. The whole question is one of extreme difficulty and has not as yet received a satisfactory solution.

The outer portions of the Sun are certainly gaseous. This is shown by the presence of lines in its spectrum, since gases only can give a line spectrum. The photosphere forms the visible disk of the Sun and is the source of the continuous spectrum. Upon the constitution of the photosphere astronomers are not in agreement. Some consider it a cloudy layer similar to clouds in our own atmosphere, but while the terrestrial clouds consist of minute water droplets suspended in the air, the solar clouds are supposed to be the condensed vapors of unknown substances floating in the atmosphere of incondensible vapors. According to the investigation of Abbot the temperature of the photosphere cannot be lower than 10,500° F. and probably not less than 11,500° F. Moissan found that all known elements volatilize at a temperature of 3,500° C. or 6,300° F. In view of these observational results it is thought by other solar physicists that clouds cannot exist in the Sun's atmosphere and that the continuous spectrum originates in the lower and denser layers under conditions in which gases would give a continuous spectrum.

As to the state of matter in the interior of the Sun we know nothing by observation, and here again the astronomers have different opinions. All agree that the temperatures in the Sun's interior are vastly higher than the surface temperature, reaching many millions of degrees, and that the pressures due to the Sun's gravitation are also tremendous near the core. As we know nothing experimentally of the behavior of matter under such extremes of temperature and pressure, the field is open for individual opinion. In view of the low average density of the Sun, one-fourth that of

the Earth or 1.4 times that of water, it is clear that very far down below the surface the Sun must still be gaseous. Those who consider that the Sun may have a solid or liquid core deduce their conclusions from the enormous pressure existing there. Those who believe that the whole interior is gaseous look at the question more from the point of view of temperature. Tho air, hydrogen, and helium, the most refractory of the elements, can be liquefied under pressures available in the laboratory, they must at the same time be below certain critical temperatures before any pressure, however great, can liquefy them. As the temperature in every part of the Sun is above the critical temperature of every known substance, the prevalent opinion is that the whole interior of the Sun is gaseous.

When the Sun is considered among a universe of stars, it is only one among hundreds of millions. The distance from its nearest known neighbor is so great that it transcends the imagination. In terms of the velocity of light its distance is about 4.4 light-years, that is, the distance traversed by light in 4.4 years with a velocity of 186,000 miles a second. There are perhaps thirty or forty stars within a radius of four times this distance. It is evident that in a sense we are quite alone in space even with a hundred million other Suns. We speak of the fixed stars, but this is a misnomer, as they are all in rapid motion, but, being so distant, their movement can only be detected by measurements of the highest precision. Our Sun is no exception, as it is sweeping thru space with a velocity of twelve and a quarter miles per second, a speed that carries the Sun and its attendant train of planets over a million miles a day, so that when the Earth has made a complete revolution around the Sun, it is still 385,000,000 miles from where it was the year before. With all this speed it would require 70,000 years to reach the nearest star, even if we were travelling in that direction.

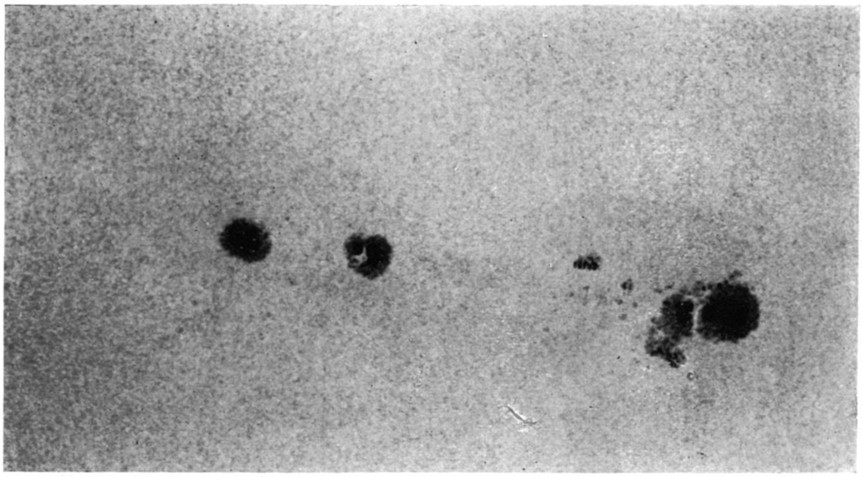
The question of very great interest is, How did our solar system come into existence and what will be its future? The evolution of the Sun takes place so slowly that no change has been noted in historical times. We cannot hope to solve its past nor to foretell its future evolution from observations on the Sun alone; but the Sun is one among the other stars and these apparently represent a series of types in a progression from a nebular stage to a dead or dying Sun. When from a knowledge gained from the study of their spectra and other characteristics the various stages in stellar evolu-

tion are found, it will be possible from its spectrum to locate the Sun in the series of evolving stars, and both its future and its past may be determined. The story is written in the ether of space and must be learned from the interpretation of the records made by the spectroscope. This is why the modern astronomer speaks and writes so continually of the spectrum and its teachings, and the layman who wishes to know the basis and not merely the results of the astronomer's conclusions will find it of great assistance to familiarize himself with the principles of spectrum analysis.*

**Note*—An excellent book for general reading is "The Sun" by Dr. Charles G. Abbot, Director of the Astrophysical Observatory of the Smithsonian Institution. The book is devoted primarily to the Sun, but may serve as an introduction to astrophysics for school and college use as well as for the general reader. Appleton and Company.

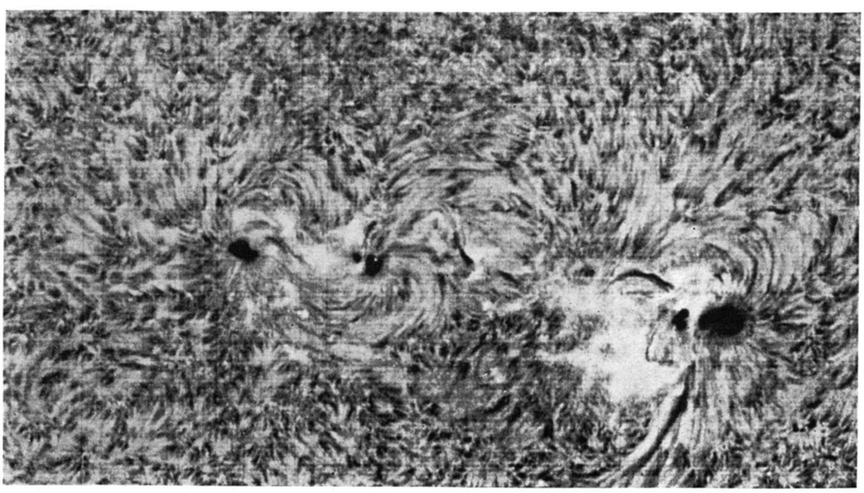
Another book for the English reader is "The Sun" by Professor R. A. Sampson, Astronomer Royal of Scotland. The aim of this little book is to provide for the general reader in small compass something like a report upon the present position of fact and theory relating to the Sun. Cambridge Press, 1914.

a



(a) Spots, granulations of the surface and faculae. Direct photograph.

b



(b) Vortical streaming of the hydrogen in the same region. Spectroheliogram.

PLATE II